An SME Decision Support System Utilising Defined Scoring Methods

Daniel Pashley
Industrial Doctorate Centre in Systems
University of Bristol
Bristol, UK
dp13092@bristol.ac.uk

Theodore Tryfonas, Andrew Crossley
Department of Civil Engineering
University of Bristol
Bristol, UK
{theo.tryfonas, andrew.crossley}@bristol.ac.uk

Chris Setchell
Imetrum Limited
Bristol, UK
chris.setchell@imetrum.com

***Abstract* — When companies engage in innovation, the appropriate selection of projects to invest resource in is paramount. In order to do this effectively, they need to research appropriate opportunities to create sufficient understanding. The various opportunities available need to be rationalised to match with the resource available. There are several rationalisation methods available, including Portfolio Management, Scoring Methods and Decision Support Systems. However, there are few that combine to be utilised by Small and Medium Sized Enterprises effectively. This work adds to the field of Small and Medium Sized Enterprise Decision Support by proposing an approach combining opportunity investigation, review and recommendation such that the most appropriate candidate innovation can be selected and taken forwards for development.**

Keywords - Portfolio Management; Scoring Methods; Decision Support Systems.

I. Introduction

Scoring methods, such as the Absolute method from [1] or the risk-reward matrix from [2], can be utilised to repeatedly review attributes of potential development projects. Selecting an innovative development approach indicates business intentions going forwards. In order to make a success of this approach, it has to be ingrained at a business wide strategic level. Businesses often form their strategy around the development of new products [3]. This can take several forms including incremental [3], radical [4],and disruptive [5]. These different strategies lead to a number of products making up the company's portfolio [6]. The difficulty for companies comes from selecting which of the next generation of potential developments should join the existing portfolio [7].

Currently there are a number of tools available to companies to aid this selection process including the Balanced Scorecard [8]. However, these methods introduce the potential for subjectivity, bias and an undue focus on particular attributes, when others may be of greater use to the company. This research and paper focuses on proposing three new methods to evaluate potential development projects that can be combined to form key elements of a Portfolio Management process.

During the process of identifying new development projects, capturing and understanding information is critical and makes a core part of this process. Utilising a process of capture, comparison and ranking, from a company's perspective, as to which are the most critical pieces of information can allow for directed capture and review. This forms a simple process, especially from the Small and Medium Sized Enterprise (SME) perspective of limited resource [9], which can result in clear understanding via prioritisation of the development options available.

There are many tools available to aid companies in making the necessary decisions, as to which development path they should select, these are a form of Decision Support Systems [10]. These use available information, of varying types per system, and a calculation method to recommend which option should be selected [10]. However, the calculation systems make decisions. They present recommendations on the decisions that should be made based on the available information; it is then up to the user to make the decision. Therefore, it is critical that Decision Support Systems are able to combine the most relevant information in a suitable way for a recommendation to be made. In some cases, utilising trends or previous data is not sufficient to deliver a recommendation. Instead the input of experts within the relevant field is required to ensure that the captured information is synthesised and understood correctly.

The aim of this work was to use the most relevant information attributes to help make recommendations on the development direction the SME should pursue. This process, while intended for a single SME, should also aim to be as universal as possible to other companies in a similar position. The underlying process used was taken from [11] and [1]. These pieces of work deliver a necessary level of understanding for company processes to reach the point at which such a method would be required. In addition, they deliver processes to capture and review relevant information on technological innovation which can be used as the basis for a Decision Support System, for this specific application.

An ethnographic stance was used to conduct this work. from a first-hand perspective [12], utilising experience of the problem space. It also requires observation of people's behaviour [13] and engagement with the problem [14] to deliver the required solution. This approach was selected in relation to an industrial problem experienced by a highly innovative SME, herein referred to as "the SME". The problem experienced was based upon the SMEs highly adaptable core intellectual property exploited in multiple technological applications. The SME has limited resource meaning that investment in innovative development projects had to be focused on those carrying the highest chance of success. Therefore, the purpose of the research project was to deliver a method to enable the appropriate selection between available possible innovative developments. This work was conducted in a cyclical manner within the SME to iteratively evolve the proposed *Decision Support System* to a point at which recommendations made could be utilised within conventional decision processes.

The paper has the following structure. Background literature is introduced to cover Portfolio Management, Strategy and Decision Making. Then the proposed *Decision Support System* is discussed and evaluated. Finally, conclusions are drawn based on the presented work.

II. Background Literature

Strategy is an instrument for keeping a high level of performance and to enable success [15]; this is focused company wide to achieve competitive advantage [16]. For a company, strategy is outlined such that it can aim to achieve set goals [17]. A company may select different types of strategy depending on what it is that they are aiming to achieve. Some strategies include first to market [16] and product differentiation [18]. In order to adopt a strategy there are three stages. The first is selection; in which a company should select a strategy which takes them towards their goals that will work across environments [19]. Once the strategy is selected, the finer details need to be formulated based on the company's knowledge [20]. Finally the strategy is implemented which requires buy in from all company levels [4] to ensure it is enacted as desired. Carefully designing and enacting strategy is critically important to differentiated activities such as innovation [4] as negative results can result from failing to be innovative in relation to the company's products or service.

The process of innovation can be seen as one whereby something new is done to bring benefit [21]. This benefit is in terms of the customer and the company performance [22]. The innovation process is so important, that it is one of the top priorities for 71% of companies [23]. However, it is an activity that pervades throughout a company including aspects such as culture, technology and resources [21]. There are several different forms of innovation. Two of the most common are process and product innovation. Process innovation is focused on the way in which firms carry out their activities [24]. Product innovation ensures the introduction of a new product to meet perceived market needs [25], based on the company's understanding. In addition to being focused on delivering something new, the innovation process is formed to be delivered in a certain way. A prime example of this is radical innovation; whereby the innovation of products or processes are driven by the technology being created, not the market [26]. This form of innovation can deliver significant returns [27] as it is reported as being responsible for 61% of profits even though it is only 38% of revenue [27]. Therefore, the innovation can be seen as a way to generate new revenue streams differentiated from the competition.

Many companies rely on innovation to achieve a competitive position within their market [7]. The challenge associated with this is assessing these opportunities [28] so the available resources can be distributed appropriately, to ensure the selected projects can be supported. With limited resources, which is always a concern, effectively managing an effective development pipeline is critical [29]. This helps to maximise returns by only allowing appropriate projects to begin. Within business, this distribution of resource is a managerial decision [30]. As such, the decision requires the necessary attention being placed on planning and understanding projects.

It is not uncommon for several options to present themselves at the same time or to be implemented together [30] alongside existing projects. However, the challenge is determining what new product has a chance of becoming a success [28]. So the question is " how to do the correct projects?" [7]. One approach is to use a conceptual funnel [31] which narrows down all potential projects into those with a higher chance of success. Activities such as investigation, evaluation and prioritising of potential projects are conducted within this conceptual funnel [29]. Prioritising potential projects, as part of the conceptual funnel, allows for an appropriate distribution of resources [7] to those projects that warrant them most. Approaches that are used to do this are either quantitative or qualitative, using techniques that range from rigorous tests to social-science methods [28].

A prominent approach to aid in the management of active and potential projects is Portfolio Management [6]. This has been developed to coordinate multiple projects towards the same strategic goals [32] and is commonly used to manage the composition of a company's product portfolio, including potential new product development [6]. This is commonly used in a planning capacity by managers or key players in an organisation [6] and ties into the management of the development pipeline [29]. As a part of this process, a primary filter can be used to draw attention to particular potential projects [2] based on attributes such as their market potential. This can aid in removing those potential projects that would not deliver on their promise or are only pitched due to internal political reasons [7].

There are several methods and frameworks discussed in literature for Portfolio Management. One method presented in [2] scores a potential project with respect to a number of criteria. However, when these same criteria are given to multiple people for review there is a strong possibility that different results are returned due to differing individual experience, making this approach highly subjective. The risk-reward matrix is also presented in [2] with the most desirable case being to have a project that is both low risk and high reward. Other methods include the organisation wide selection process in [33], the data envelopment analysis and Balanced Scorecard method in [34]. Additional methods are also presented in [7], [28], [35].

When using the presented methods, decision attributes that are commonly used are cost-benefit and cash-flow [35]. These are converted into a single determinant such as Net Present Value (NPV) or Internal Rate of Return (IRR) [7] so that they can be readily compared. However, there are several attributes that are unable to be converted into a financial measure. These include risk, route to market and engagement opportunities; all critical aspects to understand in relation to a potential technology development. Therefore, by using purely financial measures, only part of the picture is seen [36]; whereas by using other attributes a more holistic view is attained. Thus, an approach is desired that can deal with multiple types of attribute and still deliver comparable measures.

Any decision made affects the future [37]. For a company, this relates to potential project selection and ultimate offering. These decisions methods can therefore be thought of as anticipatory [38] in the way that they try to anticipate the future and make the best decision for it. An anticipated future could be caused by their introduction of a new product or service and is related to their Portfolio Management approach. Therefore, Portfolio Management is concerned with the future [39] and ensuring a company is set to be as prepared and positioned as best it can to cope with the identified futures. To aid in this, Decision Support Systems are used by decisions makers, via a set of computerised methods which capture multiple data points [10]. These are best adopted to cater for the inherent uncertainty in Portfolio Management [40] coming from the environment and the nature of the data collected. It is common for companies to collect vast amounts of data in relation to potential developments; however extracting something meaningful from it is the true challenge [41]. Decision Support Systems can help by utilising this collected data to deliver guidance on selecting a course of action. There are several forms of Decision Support Systems including data driven, model driven and knowledge driven [10]. Each form uses a variety of inputs to deliver a recommendation on how to approach the future that can then be enacted by the company.

A different slant needs to be taken when relating the previous concepts of business strategy, innovation, Portfolio Management and decision making to SMEs. SMEs are more flexible in terms of structure, meaning they can be more ambitious than their size would otherwise suggest [42]. However, their owners and managers fear loss often more than the gain [42], often hindering the attainment of success. Yet they can be highly innovative in achieving their objectives. For SMEs, innovating is a necessity for survival [43]. However, being innovative relies on a riskier business strategy [44]. Furthermore, SMEs can find it hard to obtain the required finance [44], skills and knowledge [45] to support their innovations. Therefore when managing their portfolios, extra care has to be taken to balance the risk of any innovative path [46]. This is because SMEs cannot afford to make decisions with inherent risk [47].

The existing literature as discussed here, presents how for SMEs, the ascertainment of their innovative strategy is fraught with difficulties. These include identifying appropriate innovations, researching and selecting between them. Conventional approaches are limited in their focus on understanding financial measures, yet this is only a segment of the overall picture. This drastically affects the Portfolio Management approach taken to focus on only those projects that present the least risk and financial impact; however, these will fail to yield the greatest return. Investigating these opportunities to encompass more attributes can deliver a deeper understanding beyond the financial, enabling the SME to reach its true potential via effective and suitable innovation.

III. A Decision Support System to Support Innovation Optioneering

Some companies have portfolios that are made up of multiple products and services. To keep operating they are required to innovate and improve the portfolio and fulfil the needs of their customers. This process of product and service improvement, whether that is incremental or radical, needs to be selected from the other available courses of action. For SMEs these decisions, as to which courses of action to back, become ever more critical due to their smaller portfolio of more specialist products and services. They are likely to have a small number of products offering them a marketable proposition. In addition, they are also limited by resources that can be committed to development. This means that they have to be extra vigilant in committing resources to developments that are more certain to deliver the next step in the company's evolution and revenue. To aid in this, there are many Decision Support Systems available. However, for an SME the focus comes down to being sure they are utilising suitable information to make their decisions as well as ensuring the collected information is used appropriately in the pursuit of the correct decisions. It is therefore proposed to deliver a *Decision Support System* designed to aid the decision process by utilising information of importance to SMEs and then by reviewing this to deliver a clear prioritisation of the development paths available. This would have the potential to improve their processes and indicate which path would bring them the highest levels of return and success.

A. *Underlying Structure*

In the process flow outlined by [11], there are several key phases for SMEs to progress through in order to move from the identification of an idea to its creation. These phases are Ideation, Research, Selection and Development. The process that was outlined in [11] details the relevant information to understand the innovation to be conducted, including prospective sources. In the Selection phase, core activities include the comparison of identified ideas using decision methods and prioritisation.

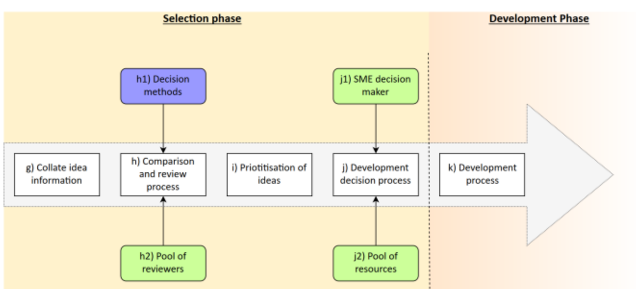


Figure 1: Selection and Development Phases from [11]

In Figure 1 it can be seen how with the collection of captured information precedes the Comparison and review process. This uses relevant Decision methods which form the basis of this paper's contribution to the body of knowledge.

The proposed *Decision Support System* uses the Weighted Sum Model at its heart. This is comprised of a weighted sum of related values [48]; which necessitates both values and their respective weights. The scores originate from the attributes identified in [11] but are aggregated together to create a description of four Scoring Factors. These were defined to be Development Potential, Resource Applicability, Commercial Viability and Payoff Expected. The Development Potential of an opportunity is defined as a metric for the likelihood for success in delivering the required technology. This can be based on the requirements of the final solution and the development process needed. The Resource Applicability describes the suitability of assigning resource to a particular project based on the amount needed and how it is to be spent. The Commercial Viability relates to how the potential development would succeed if it were entered into its respective market in the face of current competition. Finally, the Payoff Expected describes the likely returns based on the proposed technology for the relative customers/end users.

As introduced in [11], there are identified to be several critical attributes to understand in order to initiate technological innovation. These were utilised as a starting point and via the ethnographic nature of this work, those identified were modified and several others were added; these are shown in Table I.

Table I: Identified Information Attributes

Attribute	**Definition**
State of the art technology	What makes up the current state of the art offerings
Technological challenge	What is identified to be the limiting factor with these
Existing protection	Are there any patents protecting these offerings
Engagement opportunities	Who can be engaged with during this development
Requirements of solution	What would the requirements of the solution be
Versions of solution	What are the possible versions of the solution
Development process	What process would be required per solution
Need for innovation	What for each solution would need making from scratch
Required resource	What resources are required; money, people etc.
Availability of resource	Is the resource available or how can it be captured
Protection	What steps can be taken to protect any development
Target market	What is the target market and its characteristics
Value to customer	What of this solution is of value to the customer

Based on the utilisation of these attributes, a complete understanding can be created in relation to a technological innovation opportunity. In particular, this is designed to be utilised from the perspective of a company aiming to undergo this process themselves.

In order to describe each Scoring Factor, these information attributes need to be combined and aggregated together. This has been achieved by utilising the logic of the Hierarchy Process Model made up of distinctive layers [49]. To understand each Scoring Factor, a breakdown will be achieved via the question of "*How is y defined?*". Then when traversing up the hierarchy, the statement "*x* is used to define *y*" is used. Based on this, the breakdown shown in Table II is created.

Table II. Scoring Factor Breakdown

Scoring Factor	**Attribute**
Development Potential	State of the art technology
	Existing protection
	Requirements of solution
	Technological challenge
	Versions of solution
	Need for innovation
	Development process
	Engagement opportunities
Resource Applicability	Requirements of solution
	Required resource
	Availability of resource
	Need for innovation
	Development process
Commercial Viability	Existing protection
	Engagement opportunities
	Target market
	Value of solution
	Competitors
Payoff Expected	Technological challenge
	Required resource
	Availability of resource
	Protection
	Value of solution
	Engagement opportunities

Based on the breakdown shown in Table II, each Scoring Factor can be defined as a summation of the information collected for each appropriate attributes. This can therefore also be used as a way to combine reviews of individual attributes into larger sections.

In addition to the Scoring Factors for the Weighted Sum Model, there are associated weighting values used to give the final score and ranking. These Scoring Factors have associated weights called: Development Risk Aversion, Resource Spending Aversion, Commercial Risk Aversion and Payoff Expected. The Development Risk Aversion weight refers to the unwillingness of a company to enter a development project that displays anything less than a complete assurance of success. The Resource Spending Aversion describes how averse the company is to committing resources of any kind to a project. Commercial Risk Aversion relates to the level at which a company views a competitive market as being unfavourable. Finally, Payoff Expected weight describes the level at which the company expects there to be a return from any investment in a development project. These weights are assigned based upon the balance of these factors and therefore forms a basic description of the company.

In addition to weighting values to represent the company using this approach, the Reviewers who will evaluate the captured information are also weighted, such that those with different knowledge and perspective will have a respective impact. In total, three different Reviewers are involved in this process. As per [11], information is collected in relation to three main areas, State of the Art, Course of Actions and Business Case. To result in an appropriate and valid score, a Reviewer must be paired with the information that best reflects their expertise. For this, three Reviewers are defined; the Technology Expert, Developer and Manager. The Technology Expert is described as someone who understands the field in relation to a specific opportunity. The Developer, is either a hardware or software developer and therefore understands the process of creating an opportunity. Finally, the Manager understands the potential business implications of selecting an opportunity to pursue, such as the cost on the business and the target market. It is expected that a different person will occupy each Reviewer role, and therefore their related weight will be set based on the worth and validity of that person's review. However, it is also possible for the same person to occupy multiple reviewer posts; in this case the setting of their weighting value is even more critical. In this eventuality, the weighting values should be set with respect to the areas where their expertise lies.

The weights are defined and calculated for the company and Reviewer profiles at the start of the process, with the company profile set once for the use of the framework. Reviewer profile weights are changed on the start of a new project when new Reviewers are involved; as shown in (1).

$$\phi = s_{\phi} \cdot \sigma_{\phi} \tag{1}$$

Where $\phi \in \{\alpha, \beta, \gamma, \delta, \varepsilon, \zeta, \eta\}$

Where α is the Development Risk Aversion Weight, β is the Commercial Risk Aversion Weight, γ is the Resource Spending Aversion Weight, δ is the Payoff Expected Weight, s is the score given and σ is calculated in (2).

$$\sigma = 1 \div r \tag{2}$$

Where r is the normalisation factor for each of the utilised scoring methods; i.e., 5

An example of this would be as shown in (3).

$$\alpha = s_\alpha \cdot \sigma_\alpha$$

$$\sigma = {}^{1}\!/_{5} \tag{3}$$

$$\alpha = 4 \cdot 0.2 = 0.8$$

This gives a weighted score relative to the Development Risk Aversion Weight, in this example. Furthermore, the Reviewer scores are weighted based on their respective importance (weighting value). The weighting value relevant to them is applied to every score they enter, this is calculated as follows where; ε is the Technology Expert Weight, ζ is the Developer Weight, η is the Manager Weight.

$$c = b \cdot \tau$$

$$\text{Where } \tau \in \{\varepsilon,\ \zeta,\ \eta\} \tag{4}$$

$$\text{This gives } \phi = c_\phi \cdot \sigma_\phi$$

In (4), b is the score entered by the Reviewer and c is the resulting score with their weighting applied. By doing this, the final score calculated is adjusted as to the relative importance of each Reviewer as defined during the setup of the Decision Support System.

The overall formula demonstrating the WSM is given in (5).

$$A_i^{WSM} = \sum_{j=1}^{n} w_j a_{ij} \tag{5}$$

$$\text{for } i = 1, 2, 3, \ldots, \text{m}$$

Where there are n criteria, m alternatives, w_j as the weight and a_{ij} is the performance criteria. An example of this over 4 criteria and weights would give (6).

$$WSM = (n_1 \cdot w_1) + (n_2 \cdot w_2) + (n_3 \cdot w_3) + (n_4 \cdot w_4) \tag{6}$$

B. Reviewing Information Attributes

The scores for each attribute are given by utilising one of three scoring methods. Scoring has been a project selection technique since its origin in the 1950's [28]. Scoring methods help to estimate how attractive a project is and, which path to take [2]. In addition, they introduce sufficient rigor in the selection process while not being overly complex to discourage use [28]. Furthermore, they can also accommodate non-quantitative or "fuzzy" and non-detailed data whilst also being customised for the organisation they are deployed in [28]. To construct the proposed scoring methods, three key properties were identified to differentiate between the types of attribute and therefore, which method can be used to apply a score. These properties are *Independent*, *Comparable* and *Bounded*. **Independent** refers to the ability of an attribute to be scored in isolation, with the score it receives being in no way related to those before or relying on those from another attribute. **Comparable** means that the only way to effectively score an attribute is through comparing it to several other instances. **Bounded** relates to the possible inputs that can be associated to that attribute, which can be of any value but will always be between two points, i.e., maximum and minimum.

Table III. Possible property combinations

Combination	Independent (I)	Comparable (C)	Bounded (B)
1	Y	Y	Y
2	Y	Y	N
3	Y	N	Y
4	Y	N	N
5	N	Y	Y
6	N	N	Y
7	N	Y	N
8	N	N	N

Not all the combinations described in Table III are possible to be applied together. Combination 1 cannot occur as attributes cannot be both Independent and Comparable due to these properties not aligning. Combinations 2 and 4 are not possible as an Independent parameter that is also non-Bounded, would effectively change each time it is used and would therefore require older versions to be changed, making it none Independent. Finally, combinations 6 and 8 are not possible as an attribute can be neither Independent nor Comparable, as they must be mutually exclusive. This leaves combinations 3, 5 and 7. Each of these combinations are derived to make a viable method of applying a score to attributes.

Table IV. Scoring methods based on property combinations

Method	Combination	I	C	B
Absolute	3	Y	N	Y
Balance	7	N	Y	N
Comparative	5	N	Y	Y

Each of the methods shown in Table IV will now be presented along with an example demonstrating their use.

The first method, *Absolute*, is based on combination 3 as shown in Table IV. In this, the attributes being reviewed can be dealt with in isolation and have no bearing on others of the same type, they do not require direct comparison to be evaluated and are bounded by the number of responses that can be taken. Therefore, this method can be thought of as a simple selection between the possible outcomes. For example, a question could be posed such as the number of geographical regions that a technology could enter; this would then be combined with six possible choices representing the number of regions. From this, the Reviewer would select that, which best fits the information they are presented with.

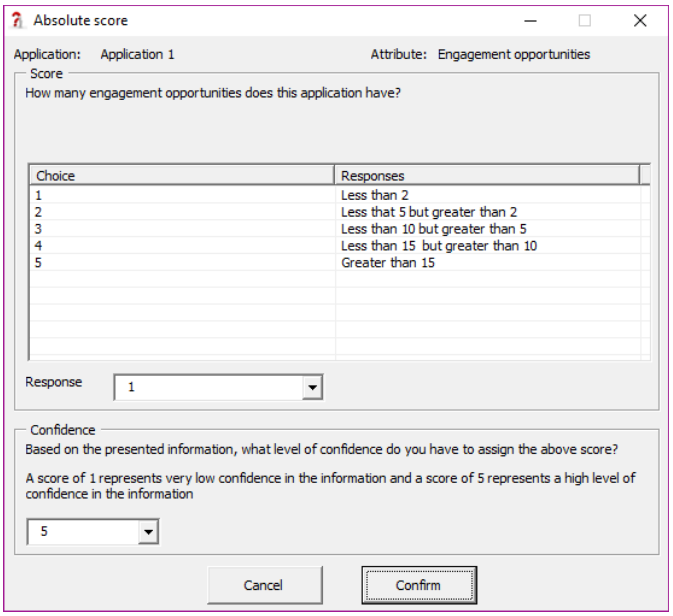


Figure 2. Absolute Scoring Method

As can be seen in Figure 2, the *Absolute* method has been coded in a Graphical User Interface (GUI) to facilitate ease of use for the Reviewer such that they can arrive at the most valid result for the question asked. In this example, they are asked about the possible number of engagement opportunities for a development opportunity. A selection is then made, based on the descriptions matching the information presented.

The second scoring method is the *Balance* method and is described by combination 7 in Table IV. The attributes being reviewed using this method cannot be treated independently; so, all previous values need updating for a new review. In addition, it is comparable and requires comparison to other values already reviewed and it is not bounded, so the values entered can be of any size. This method is used to evaluate financial attributes, due to their unbounded nature. The required process is more complex than the *Absolute* method due to several rules being followed to deliver a normalised final score per attribute. These are based on the concept of a normalised scale onto, which all attributes are scored. In principle, this can be thought of as a numbered scale ranging from a lower bound to a maximum with steps in between; one and five with incremental steps of one, for example. This would result in a normalised scale with five fixed positions (normalised scores). When a value is entered, from a calculation of cost for example, this new value is compared to all those already entered to deliver the normalised score. If this attribute is the first to be entered, it is assigned the middle position on the normalised scale, in the case of the one to five example given, this would result in a normalised score of three. When there are two attributes entered, these are assigned to the extremes of the normalised scale, resulting in one and five as normalised scores in the example given earlier. When additional values are entered, a calculation is required to achieve a certain normalised score. This value is called Step Change and is given by (7).

$$Step\ Change = (Largest\ Value\ - Smallest\ Value) \div Numberof\ Step \qquad (7)$$

With this value for Step Change, it is added onto the lowest value on the scale accumulatively until the maximum value is reached. Utilising these at each point on the normalised scale, all remaining entries are evaluated. In effect, these values form barriers for, which those entered must be larger than to progress to the next normalised score.

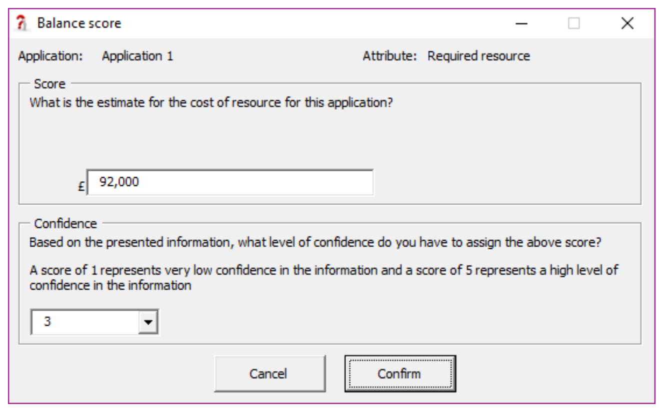


Figure 3: Balance Scoring Method

In Figure 3, the *Balance* methods GUI can be seen. This presents a question to the Reviewer along with a place to entered their calculation for cost of all resources for the application at hand.

The final method is named *Comparative*, due to its structure necessitating comparisons. This method is for use with complex attributes or those that can be defined as "fuzzy" and are difficult to assign an absolute value on, which to base multiple perceptions of the same problem. To enable this method, the pairwise comparison process and underlying calculations of the Analytic Hierarchy Process (AHP) are utilised. Using these comparisons, it is easier to define preference between sets of options than defining absolute values. This is presented to the Reviewer through a series of comparisons based on a range of values representing the whole normalised scale in use. As with the *Balance* method, the normalised scale is defined between two values with a defined step size between them. The normalised scale is used once the values from the AHP are calculated, following the completion of the pairwise comparisons. All values of the AHP calculations can always be summed to 1. The normalisation process occurs with these scores. For this process, a number of rules are followed to deliver the normalised score. If there is only one value to review, the middle score on the normalised scale is automatically assigned. From here, values are assigned to the fixed positions on the normalised scale around the centre until all are filled. Next, the largest and smallest values are placed at the extremes of the normalised scale, with the remaining being evenly distributed between them. With this distribution complete, the values are rounded down to the next normalised score available.

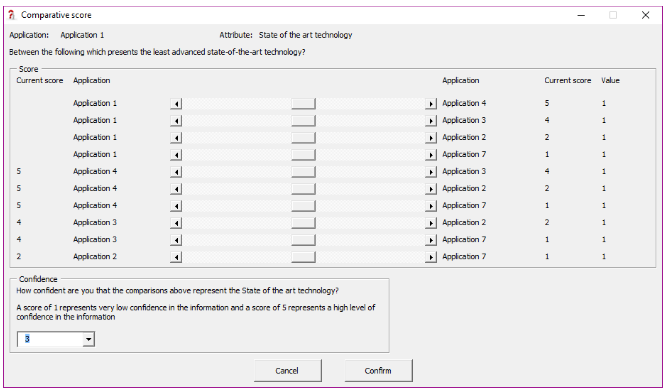


Figure 4: Comparative Scoring Method

In Figure 4, the pairwise comparison method between combinations of opportunities with respect to a single attribute can be seen. To conduct the comparison, the slider for each pair is moved to one of the possible nine positions to demonstrate a level of preference between the opportunities based on the presented information in each case.

Table V: Scoring Methods per Attribute

Attribute	**Assigned method**
State of the art technology	Comparative
Technological challenge	Comparative
Existing protection	Comparative
Engagement opportunities	Absolute
Requirements of solution	Comparative
Versions of solution	Absolute
Development process	Comparative
Need for innovation	Comparative
Required resource	Balance
Availability of resource	Comparative
Protection	Comparative
Target market	Comparative
Value to customer	Comparative

Using each of the three scoring methods, *Absolute*, *Balance* and *Comparative*, it is possible to review any attribute by appropriate selection, based on the three principles in Table IV. They can then result in reduced bias on the final scores calculated in each case, meaning a more repeatable and trustworthy outcome is reached.

As shown in Table V, each attribute has a Scoring Method assigned to enable the review of captured information. These were selected based on the definition of each method shown in Table IV.

Each of these reviews for the defined attributes is combined with a measure of uncertainty in relation to the conducted review. This measure of uncertainty allows for the review to consider the quality, amount and source of information. With this, a poor quality, inadequate or untrustworthy source can have its review score graded downwards so it does not have the same level of impact as that from an industry expert for example. This is based on work by [50]. In application, this is defined as "Certainty" in the review that has been conducted as shown in (8). The values entered by each Reviewer are utilised to weight down their respective scores.

$$b = d \cdot (c \div g) \tag{8}$$

Where d is the calculated Certainty score, c is the selected Certainty by the Reviewer, g is the range of possible Certainty scores, d is the entered score by the Reviewer and b is the adjusted review score for Certainty.

The level of certainty entered by the Reviewer can be seen in Figure 2, Figure 3 and Figure 4 at the bottom of each console. In each of these, the Reviewer selects from a five-point scale with five representing complete confidence in the review completed and one being very low confidence. This is driven by the information they are presented with and the understanding it delivers in relation to the opportunity in question.

C. *Calculation and Use of Final Score and Ranking*

With this calculation for Certainty, the overall calculation for the final score for an application is as follows. It is important to note how the calculated scores are not done so in any specified units, with larger scores showing a more suitable application. The scores for each factor are calculated upon the completion of the entry for the grading for a proposed technological innovation. This is a summation for all values entered in relation to each factor to be used in the later calculation of the final score; this is demonstrated in (9).

$$E = \{b \in R | 0 < b \leq r\}$$

$$\psi = \sum E_{\psi} \tag{9}$$

Where $\psi \in \{ \theta, \iota, \kappa, \lambda\}$

Where θ is Development Risk Aversion Score, ι is the Commercial Risk Aversion Score, κ is the Resource Spending Aversion Score and λ is the Payoff Expected Score.

This is calculated based on the scores for each factor and its associated weight value using the WSM described earlier as shown in (10).

$$F = \theta \cdot \alpha + \iota \cdot \beta + \kappa \cdot \gamma + \lambda \cdot \delta \qquad (10)$$

Where *F* is the final score for the application.

In addition, based on the certainty values entered earlier for each review, an overall certainty of the application is calculated. This demonstrates the potential variability of the final score based upon the values entered. The benefit is that when reviewing the results, the potential maximum and minimum score for an application can be seen; which can be used for deeper levels of comparison. This utilises the core method described in [50] and is demonstrated in (11) and (12).

$$Initial\ CF = w_1 \cdot x_1$$

$$Current\ CF = Previous\ CF + (1 - Previous\ CF) \cdot (w_i \cdot x_i) \qquad (11)$$

$$Uncertainty = 1 - Total\ CF$$

Where *w* is the weight between 1 and 0 and *x* is the value. The second calculation in the process is repeated as required based on the available weights and values. To utilise this method, the entered confidence values by each of the three Reviewers are averaged and then utilised in (10).

$$h = \bar{t} \cdot \varepsilon \qquad \text{Where}$$

$$p = h + (1 - h) \cdot (\bar{y} \cdot \zeta) \qquad \text{Where} \qquad (12)$$

$$q = p + (1 - p) \cdot (\bar{u} \cdot \eta) \qquad \text{Where}$$

$$v = F \cdot q$$

Where $\bar{t}$ is the Technology Expert average confidence, $\bar{y}$ is the Developer average confidence, $\bar{u}$ is the Manager average confidence, h is the initial Certainty calculation, p is the second Certainty calculation, q is the third Certainty calculation and v is the relative uncertainty.

Based on these, results are calculated such as those in Figure 5. The examples shown are not from any particular commercial projects.

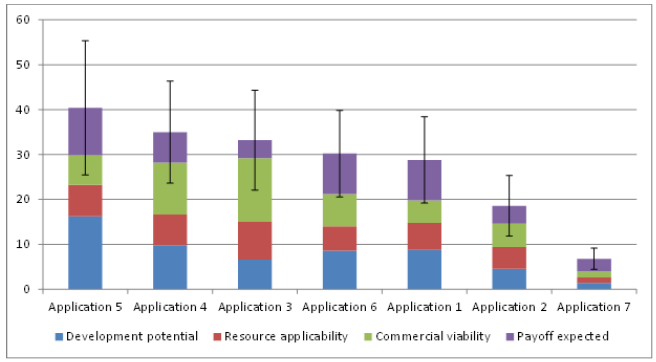


Figure 5: Example Results Export

The results from the calculations are shown in Figure 5. The overall score from the Weighted Sum Model are given by the overall score from each bar and the results for each segment coming from the Scoring Factors. Onto each of these, the calculated certainty is added in the form of an error bar. In the example shown, there are several conclusions that can be drawn based on the overall scores and the sizes of each segment of the bars. For example, it can be seen how Application 3 shows significantly greater Commercial Viability than the other applications; whereas Application 5 shows the greatest Development Potential. It is these aspects that aid in the selection process, not only the overall score; therefore, the additional visibility that is delivered by this approach can be seen, making it more than a pure ranking of opportunities.

A threshold is placed onto this, to demonstrate the potential development paths that carry the most worth and should therefore be considered by the company decision makers. This threshold is to be devised by the company using this approach such that the relevant number of opportunities are taken forwards for consideration. As with a greater number of suitable opportunities taken forwards, the chance for selecting the one that delivers the desired success increases. Considering the graph shown in Figure 5 with a threshold set at 30, only the top three applications would be deemed to be worthy of consideration for the distribution of resources. In addition, Application 6 would be sitting on the threshold with Application 1 being close behind, showing clear potential but not sufficient to pass outright. Therefore, in this case, additional research would be required to deliver a clear indication one way or another.

Attribute	Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7
State of the art technology	1.8	0.6	2.4	3	3.2	1.2	0.8
Technology challenge	1.8	1.6	0	2	2.4	0.6	0.6
Existing protection	0.6	0.8	0.4	0.6	0	3	0
Engagement opportunities	0.8	0.8	5	5	0.8	3	0.8
Requirements of solution	1.8	0.8	3.2	3	1.6	0.6	0
Versions of solution	1	0	0	0	5	0	0
Development process	1.8	1.6	3.2	3	2.4	0.6	0.6
Need for innovation	0	1.2	2.4	0	1.8	0	0
Required resource	0.6	1.2	1.2	1.8	1.2	3	0.6
Availability of resource	1.8	0	1.6	0	0	1.2	0
Protection	2.4	0.6	0	1.2	3	1.8	0.8
Target market	1.8	0.8	0.6	1.2	4	3.2	0
Value of solution	2.4	0.6	1.2	1.8	4	2.4	0.8

Figure 6. Normalised Scores with applied Certainty

Finally, Applications 2 and 7 would demonstrate a score to be significantly below that of the threshold, meaning these options should not selected for additional research to potentially increase their scores to a point whereby they could be considered. Using such a threshold, a clear indication can be given as to the opportunities worthy of consideration, as only picking that with the largest score is an unsuitable technique.

In addition to the ability to present a ranking based around four scoring factors and the related certainty, further visibility of the cause of these scores is reached via a breakdown of the review and calculation stages.

As shown in Figure 6, the individual scores per application and attribute can be seen. This increases the utility of this approach by delivering visibility of the exact attributes where an opportunity achieves better or worse scores than those they are being compared to. By presenting this information, the decision-making process can be further aided by demonstrating not only, which opportunity presents the greatest scores with respect to the Scoring Factors, but also, which particular attributes are responsible. This can aid in deciding between two opportunities with very similar overall scores.

Overall, the proposed Decision Support System has been built into an application that provides a GUI to each identified role as to increase the ease of use. It has two user classes, Admin and Reviewer. The Admin class is responsible for setting profile weights, adding Reviewers and creating new opportunity investigations and assigning them to the appropriate Researcher and Reviewer. In a conventional implementation, the usage procedure would be as follows.

Firstly, the Amin class of user is required to set up the Decision Support System for use. This involves defining the company position via the use of the weighting values. The weighting values are also required to be set for the Reviewers based on who will carry out the review process. From here, the development opportunities to be investigated are added and the Reviewers assigned. Following this, the Researcher will use the defined information capture procedure based on [11] and the expansion of the required attributes shown in Table I, to capture an understanding of the development opportunity at hand. From here, the Reviewers will deliver their scores by utilising the defined Scoring Methods outlined. Once this is completed, the final score and ranking will be automatically produced for exporting by the Admin class user. It is important to note, how the user experience alters, based upon their classification. Throughout the appendices, various screenshots are shown of the interface for the devised Decision Support System.

IV. System Evaluation

To evaluate the proposed *Decision Support System*, several internal evaluations were conducted within the SME. These involved most staff and utilised several previous opportunity investigations analysed by the proposed system. Due to these still being commercially sensitive, they cannot be discussed in detail. In addition, due to this confidentiality and the limitations in staff numbers, it is acknowledged that the population size used for this evaluation was limited, yet it represented most of the company. Two separate areas of evaluation were conducted; the first analysed the performance of the described scoring methods and the second focused on the acceptance and validity of the recommendations made by the *Decision Support System*. The evaluation of the scoring methods is limited to the *Comparative* method alone due to this being the most complex. The *Absolute* and *Balance* methods required simple selections or calculations of values to result in the Normalised Score.

The first area of evaluation investigated the consistency of the *Comparative* method as this is the method used the most due to most attributes being complex and “fuzzy” in nature. To do this, a commonly used technique based on selecting a score from a set number of categories was compared to. For this, several opportunities were presented to several staff within the SME along with a defined set of categories to score them and the *Comparative* method. For both methods, scores were assigned to each of the five opportunities and also a position in a ranking. In the case of the category based method, the scores were assigned utilising a set of criteria and the ranking based upon each opportunity being placed in positions 1 – 5. For the *Comparative* method, the scores were extracted from the method before normalisation and the final ranking was obtained following normalisation. As the *Comparative* method calculates the scores of each opportunity in a way that always sums to one, the scores assigned utilising the category based method would require normalisation to allow for comparison. This normalisation is shown in (13).

$$A = \begin{pmatrix} A_{11} & \cdots & A_{1N} \\ \vdots & \ddots & \vdots \\ A_{N1} & \cdots & A_{NN} \end{pmatrix}$$

$$A_{11} + A_{12} + \cdots A_{1N} = \sum_{n=1}^{N} A_{1n} \tag{13}$$

$$C_{ij} = \begin{cases} \dfrac{1}{\sum_{n=1}^{N} A_{ij}}, & i = j \\ 0, & i \neq j \end{cases}$$

$$B = C \cdot A$$

Where A is a matrix of entered score values, C is matrix for scaling each row and B is the normalised matrix.

In addition, in several cases it was required that outliers were removed for effective statistical analysis. This was due to participants delivering scores or ranking values that were significantly different from the others, meaning direction comparisons and averaging was disrupted. For this, the Median Absolute Deviation method was utilised as this demonstrates significant robustness to outliers. The equation for this is given in (14).

$$MAD(\{Y_i\}_{i=1\cdots N}) = median(\{|Y_i - median(\{Y_i\}_{i=1\cdots N})|\}_{i=1\cdots N}) \tag{14}$$

Where Y is a collection of numbers.

To compare the results from each aspect of this evaluation, the participant's scores and rankings were averaged; this allowed for direct method comparison between the two approaches. Averages were also conducted per method based on those from the previous step to show the overall similarities between methods. In addition, the participants were grouped together with respect to their roles within the SME. The scores and rankings entered were also averaged per role group to investigate if participants were like their colleagues from similar backgrounds and skillsets. In addition, following the completion of both aspects of this evaluation, several questions were asked of each participant in the form of a questionnaire to obtain their opinions about the process they just experienced. This will add further insight into the preference between the two methods and experience in use, even if the results from the comparisons prove inconclusive or unexpected in any way.

For the presentation of evaluation results, the Category method is abbreviated to CAM and the Comparative method is abbreviated to COM. In addition, "WO/O" will stand for "Without Outliers".

Table VI: Application Score Variances with and without Outliers

	Applications					
Method	**1**	**2**	**3**	**4**	**5**	**Average**
CAM	0.004	0.004	0.003	0.004	0.005	0.004
COM	0.017	0.006	0.020	0.015	0.023	0.016
CAM - WO/O	0.004	0.004	0.001	0.004	0.003	0.003
COM-WO/O	0.001	0.001	0.020	0.015	0.015	0.010

The results presented in Table VI lead to several conclusions about the two methods evaluated. Firstly, in the case where outliers were not removed, the category based method demonstrated consistently lower variance per application. This is due to the nature of the way the scores are selected for this approach being defined and can therefore only be of five possibilities in this case; whereas the *Comparative* method utilises a calculation approach based upon 90 possible positions of the sliders for the pairwise comparisons. This results in significantly more variability leading into the score calculations. In the second half of Table VI, several outliers are removed, resulting in more equality between the two methods. This demonstrates the sensitivity of the *Comparative* method in its calculations based upon the positions of the results of the pairwise comparisons.

Table VII. Application Ranking Position Variance

	Applications					
Method	**1**	**2**	**3**	**4**	**5**	**Average**
CAM	1.69	0.69	2.01	1.64	2.69	1.744
COM	1.76	1.56	1.01	1.01	3.09	1.686

In Table VII, the average ranking assigned to each application by both methods can be seen. The number demonstrated by each method to have the lowest variance is roughly equal. However, the two applications whereby the *Comparative* method demonstrated lower variability (application 3 and 4) was significantly more so that the others; which were much closer between each method. This illustrates how these two cases were positioned more favourably during the pairwise comparisons by most of the SME's participants. Again, the calculated ranking is shown to be sensitive to the increased number of positions in the pairwise comparison, yet the average across all applications is very similar. This points towards each method being equally capable of being used for delivering consistent rankings over a wide range of participant backgrounds and skills.

Table VIII: Participant Group Score Variance

	Participant Group				
Method	**Software Developer**	**Sales**	**Office & Admin**	**Applications Support**	**Tech**
CAM	0.003	0.001	0.0004	0.001	0.001
COM	0.016	0.010	0.001	0.009	0.010

The results presented in Table VIII present the variance per participant group; in each of the groups, there are two participants. These results show how the category based method delivers increased consistency within the same participant groups, showing how similarly people view information based on their background and skillset. Again, this demonstrates the sensitivity of the *Comparative* method between positions selected by the user as to the score calculated.

Table IX. Participant Group Ranking Positions

	Participant Group				
Method	**Software Developer**	**Sales**	**Office & Admin**	**Applications Support**	**Tech**
CAM	1.80	1.30	1.80	0.30	1.80
COM	0.60	0.80	0.10	0.85	1.40

In Table IX, the variance of the ranking positions calculated per participant group is shown; based upon the same groups as those used in Table VIII. Here, it can be seen how the *Comparative* method delivers repeatedly greater levels of consistency within participant groups than the category based method. This is due to the defined calculation process converting the scores entered by the participant into the normalised ranking. Whereas, using the category based approach, this is done manually, and therefore the difference in approaches becomes apparent. This therefore demonstrates the utility of this method in delivering consistent reviews over participants but the careful selection of those to deliver the review is important. Such a decision should be made by the company's management prior to the evaluation based on availability, skillset and experience. This may also highlight to those selecting the Reviewers that the SME lacks in certain skills or experiences, and should endeavour to fill these gaps.

This evaluation has resulted in understanding several aspects of the defined scoring method. Firstly, the delivery of scores is more sensitive than a category based approach, which is more commonly used, due to the increased number of possibilities the Reviewer can select. When viewing an entire population, containing those of several different backgrounds and skillsets, the resulting ranking is also less consistent. However, when comparing those of a similar background and skillset, the results become far more consistent. This case is far more likely in actual use, whereby those of a similar background and skillset are selected to review the same information for each opportunity, leading to increased consistency and comparability between cases.

Following the scoring aspect of the evaluations, the participants were asked several questions in relation to their perception on the two presented methods of delivering scores and rankings in the form of a questionnaire. This specifically related to their preference between them and any problems they could foresee. The general feedback illustrated a perception that using the category based method would lead to difficulty with larger datasets. In addition, this method was noted to be more difficult to deploy, as the definition of each scoring category was not a perfect description of the opportunities for evaluation. Furthermore, participants noted how their internal definition of categories would differ between multiple Reviewers, reducing comparability. In relation to the *Comparative* method, this was better received due to the ease of use and the reduced comprehension required for the application of scores. This was due to the configuration necessitating only a comparison to other opportunities. It was also perceived that this approach would lead to increase consistency due to the defined approach. However, during the evaluation it was noted to be more consistent, but only when compared to those of a similar background. Nonetheless, this would be more representative of an actual implementation, with those from similar backgrounds reviewing the same information attributes, leading to greater consistency and comparability.

The next stage of the evaluation focused on the acceptance of the resulting ranking and the success experienced by those opportunities selected to be taken forwards based upon the *Decision Support Systems* recommendations. To conduct this evaluation, a semi-formal interview process, driven via the use of a questionnaire, was conducted with the SME's decision maker, the Managing Director. For this, questions were asked in relation to the created ranking, the ease of understanding, successes of selected opportunities and changes that would be made in hindsight.

Based on presented results rankings from the proposed *Decision Support System*, clear understanding could be attained as to the position of opportunities within the ranking. This also included where each opportunity was positioned within the ranking and the aspects leading to this, based upon the four scoring factors. Furthermore, the uncertainty presented indicated to the Managing Director, which opportunities were the riskiest, due to the size of the error bar. It was also noted how succinct information on each opportunity would be required alongside the graphical information to make a decision. Furthermore, it would also be required to include aspects of day-to-day operations in comparison to these development opportunities to decide on how to proceed. These points illustrate trust in the presented information and a utility to the decision-making process, but the necessity for several additions in the future.

The second element of this evaluation was to gauge the success of the opportunities selected to be taken forwards because of the recommendations made. This would be utilised to evaluate whether they were the right decisions in retrospect. Over the course of the Decisions Support Systems development, two opportunities were selected to be taken forwards. One was a software add-on to the SME's existing product range, with the other becoming a project made up of several individual opportunities that were closely related. Since introduction, the software add-on has experienced significant industrial attention but with slow adoption, increasing from 2 sales in year 1 to 18 by the end of the second quarter of year 3. This means an accumulative value of approximately £130k, not including additional system costs. The Managing Director noted how this new product has received significant attention, which is promising, yet it has not converted into sufficient orders to generate the desired revenue. This was judged to be due to there being limited features as a part of this offering, resulting in aspects of the related tests being incompatible with the current offering. For it to be considered a complete success it was noted that this offering would be required to increase its capabilities to encompass the remaining features and to result in a step change in orders to match the industrial attention observed.

The second opportunity taken forwards, comprised of several related opportunities, was selected on the promise of creating a new business segment for the SME and offering significant returns due to displacing existing technologies noted to have several limitations. However, due to the resource constraints of the SME, funding was sought from an external source. This funding was not obtained due to the competition nature of the funding source; meaning this project has progress little past an extended evaluation of the technology and market. Yet the Managing Director still viewed this selection as the right course of action, given the information available and recommendations made. It was also viewed to be the path to take these applications forwards as a group rather than individually as these would present the greatest return in this way; while offering an increased number of avenues to investigate for taking this project forwards.

Finally, the main outcome was that both opportunities were selected, utilising the recommendations made, aligning with those making the company decisions. As yet neither has progressed to the point desired due to the ability of the SME to fund and advance these products to the desired stage. Therefore, the potential success of the selected business opportunities is a constraint of the SME rather than of the *Decision Support System*. To more accurately analyse the recommendations made, a more time would be required for those opportunities already selected and for a greater number of new ones to also be selected and progress to market. Following this, a more in-depth analysis can be conducted.

V. Discussion and Conclusion

Based on the *Decision Support System* presented, several conclusions can be drawn. The underlying structure used [11], delivered the process required for companies such as the SME for the investigation of innovation opportunities. Using this in combination with the ethnographic process for this work, several enhancements and additions were made to the information capture process to increase the overall company knowledge in relation to an opportunity. This structure also highlighted the requirement for the decision point to come after the capture of information, using defined scoring methods. The advantage of this is that decisions can be made based on like-for-like information due to each opportunity having the same points researched.

Using the defined scoring methods, the same attributes from different potential opportunities can be directly compared after conversion into a numerical form on the same normalised scale. This can deliver an understanding of where certain opportunities are stronger than others. Secondly, it is very flexible for the company, as any attribute can be scored using the outlined methods. Therefore, only the information that is important to the company is analysed. The approach also diminishes the impact of subjectivity on the final score. By defining the review process to be one of three methods, the results found from different points of view should be very similar; meaning consistent results can be achieved irrespective of who is conducting the review. Bias and personal influence can also be minimised as the final score is not created based on discussion but rather the generation of numerical scores. However, there is the chance for outliers in the scoring process, more commonly seen from those from unsuitable backgrounds or skillsets.

These scoring methods individually deliver significant capabilities to the decision-making process by converting all attributes to the same scale for direct comparison. This is extended further through the addition of information certainty. This allows for the calculated score to be effectively weighted down, depending on the confidence of the Reviewer in the information presented. The advantage this delivers is that untrustworthy information will not have the same level of impact on the calculation of the scores and ranking as that from a reputable source. This achieves a greater level of control over the score and ranking and reduces the influence of poor information.

The scores calculated, and weighting values entered are then combined using the Weighted Sum Model. This simpler approach allows for the utilisation of calculated values and measures representing the company in place of weights, to result in a final score. The advantage of this is the visibility of the scores calculated and therefore the final position in the ranking, delivering traceability.

With the final score and ranking calculated via the defined scoring methods, certainty values and the Weighted Sum Model, a threshold can be applied. This reflects the company's position, as the decision threshold value can be set at the appropriate level. For companies with limited resources, such as SMEs [9], this threshold level can be increased such that potential development projects have to display a higher level of certainty of success before considering them. This threshold completes the recommendations made by this *Decision Support System* by indicating those opportunities that should be taken forwards for a selection process. This can be implemented by any SME in a similar position through stages of capturing information, defining their company position, profiling the Reviewers, scoring the information and certainty and applying a threshold to the final score and ranking.

Concluding, we could firstly say that the *Comparative* method demonstrates increased sensitivity in relation to the scores, due to the number of positions possible during use. However, due to the defined nature of the normalisation process, these scores are converted into a more consistent ranking in comparison to those of a similar background. This is representative of a real-life application whereby those reviewing the same information would be assigned this due to their experience and background. Finally, the recommendations delivered are understandable and trustworthy within the environment where this *Decision Support System* was created. In addition, those opportunities recommended to be taken forwards displayed reasonable levels of success given the ability of the SME to fund their development.

There can be seen to be several ways this *Decision Support System* has deliver impact to the SME and has potential to the wider field. To the SME, the internal product assessment procedure has been changed, to include the structure demonstrated by the *Decision Support System*. This restructures their information capturing efforts in relation to innovation opportunities, the review of this information, and the decision processes. Altogether this has delivered a more professional assessment process over the conventional ad-hoc approach commonplace with SMEs without burdening them with unnecessary activities. To the wider field, this *Decision Support System* and its information capture method can deliver several improvements. The defined information capturing process results in directly comparable opportunities due to the same attributes for each being understood. These can then be reviewed by a defined scoring method, irrelevant of their type. The calculation method offers simplistic creation of a representative score for the opportunity, based on the results of the scoring methods and the representatives of a company. Overall, this results in a complete modelling and assessment of opportunities to hand. Therefore, the approach outlined in this work forms a practical method to investigate, evaluate and select from available opportunities to direct a company's innovation activities.

ACKNOWLEDGMENT

This work was supported by the Systems Centre and the EPSRC funded Industrial Doctorate Centre in Systems (Grant EP/G037353/1) and Imetrum Limited.

REFERENCES

[1] D. Pashley, T. Tryfonas, A. Crossley, and C. Setchell, "Scoring Methods to Enable Bespoke Portfolio Management," in *ICONS 2017 : The Twelfth International Conference on Systems Scoring*, 2017, pp. 54–61.

[2] R. Mitchell, R. Phaal, and N. Athanassopoulou, "Scoring methods for prioritizing and selecting innovation projects," *PICMET 2014 - Portl. Int. Cent. Manag. Eng. Technol. Proc. Infrastruct. Serv. Integr.*, no. 2001, pp. 907–920, 2014.

[3] A. N. Kiss and P. S. Barr, "New Product Development Strategy Implementation Duration and New Venture Performance: A Contingency-Based Perspective," *J. Manage.*, pp. 1–26, 2014.

[4] K. R. Jespersen and R. Bysted, "Implementing New Product Development: a Study of Personal Characteristics Among Managers," *Int. J. Innov. Manag.*, vol. 20, no. 3, pp. 1–23, 2016.

[5] D.-J. Lim and T. R. Anderson, "Technology trajectory mapping using data envelopment analysis: the ex ante use of disruptive innovation theory on flat panel technologies," *R&D Manag.*, no. 1973, p. n/a-n/a, 2015.

[6] M. G. Kaiser, F. El Arbi, and F. Ahlemann, "Successful project portfolio management beyond project selection techniques: Understanding the role of structural alignment," *Int. J. Proj. Manag.*, vol. 33, no. 1, pp. 126–139, 2015.

[7] M. Abbassi, M. Ashrafi, and E. Sharifi Tashnizi, "Selecting balanced portfolios of R&D projects with interdependencies: A cross-entropy based methodology," *Technovation*, vol. 34, no. 1, pp. 54–63, 2014.

[8] E. Tapinos, R. G. Dyson, and M. Meadows, "Does the balanced scorecard make a difference to the strategy development process?," *J. Oper. Res. Soc.*, vol. 62, no. 5, pp. 888–899, 2011.

[9] R. McAdam, R. Reid, and M. Shevlin, "Determinants for innovation implementation at SME and inter SME levels within peripheral regions," *Int. J. Entrep. Behav. Res.*, vol. 20, no. 1, pp. 66–90, 2014.

[10] G. D'Aniello, A. Gaeta, M. Gaeta, M. Lepore, F. Orciuoli,

and O. Troisi, “A new DSS based on situation awareness for smart commerce environments,” *J. Ambient Intell. Humaniz. Comput.*, vol. 7, no. 1, pp. 47–61, 2016.

[11] D. Pashley, T. Tryfonas, A. Crossley, and C. Setchell, “A Directed Research Approach for repeatable SME decision making,” *J. Syst. Sci. Syst. Eng.*, no. Under review at time of submission.

[12] S. Lahlou, S. Le Bellu, and S. Boesen-Mariani, “Subjective Evidence Based Ethnography: Method and Applications,” *Integr. Psychol. Behav. Sci.*, vol. 49, no. 2, pp. 216–238, 2015.

[13] K. Kashimura, Y. Tsukada, T. Kawasaki, H. Kitagawa, and Y. Maruyama, “Design approach based on social science for social innovation business,” *Hitachi Rev.*, vol. 63, no. 9, pp. 548–559, 2014.

[14] R. L. Baskerville and M. D. Myers, “Design ethnography in information systems,” *Inf. Syst. J.*, vol. 25, no. 1, pp. 23–46, 2015.

[15] A. Ghezzi, “Revisiting business strategy under discontinuity,” *Manag. Decis.*, vol. 51, no. 7, pp. 1326–1358, 2013.

[16] S. F. Slater, E. M. Olson, and C. Finnegan, “Business strategy, marketing organization culture, and performance,” *Mark. Lett.*, vol. 22, no. 3, pp. 227–242, 2011.

[17] S. Soltanizadeh, S. Z. A. Rasid, N. M. Golshan, and W. K. W. Ismail, “Business strategy, enterprise risk management and organizational performance,” *Manag. Res. Rev.*, vol. 39, no. 9, pp. 1016–1033, 2016.

[18] K. A. Bentley, T. C. Omer, and N. Y. Sharp, “Business strategy, financial reporting irregularities, and audit effort,” *Contemp. Account. Res.*, vol. 30, no. 2, pp. 780–817, 2013.

[19] F. Lieder and T. L. Griffiths, “When to use which heuristic: A rational solution to the strategy selection problem,” *Proc. 37th Annu. Conf. Cogn. Sci. Soc.*, vol. 1, no. 3, pp. 1–6, 2015.

[20] M. Y. Brannen and C. J. Voisey, “Global Strategy Formulation and Learning From the Field : Three Modes of Comparative Learning and a Case,” *Glob. Strateg. J.*, vol. 2, pp. 51–70, 2012.

[21] L. Bucciarelli, “A Review of Innovation and Change Management: Stage Model and Power Influences,” *Univers. J. Manag.*, vol. 3, no. 1, pp. 36–42, 2015.

[22] C. Baden-Fuller and S. Haefliger, “Business Models and Technological Innovation,” *Long Range Plann.*, vol. 46, no. 6, pp. 419–426, 2013.

[23] S. F. Slater, J. J. Mohr, and S. Sengupta, “Radical product innovation capability: Literature review, synthesis, and illustrative research propositions,” *J. Prod. Innov. Manag.*, vol. 31, no. 3, pp. 552–566, 2014.

[24] J. L. Hervas-Oliver, C. Boronat-Moll, and F. Sempere-Ripoll, “On Process Innovation Capabilities in SMEs: A Taxonomy of Process-Oriented Innovative SMEs,” *J. Small Bus. Manag.*, vol. 54, no. April 2015, pp. 113–134, 2016.

[25] C. F. Cheng, M. L. Chang, and C. S. Li, “Configural paths to successful product innovation,” *J. Bus. Res.*, vol. 66, no. 12, pp. 2561–2573, 2013.

[26] D. A. Norman and R. Verganti, “Incremental and Radical Innovation: Design Research vs. Technology and Meaning Change,” *Des. Issues*, vol. 30, no. 1, pp. 78–96, 2014.

[27] W. E. Baker, J. M. Sinkula, A. Grinstein, and S. Rosenzweig, “The effect of radical innovation in/congruence on new product performance,” *Ind. Mark. Manag.*, vol. 43, no. 8, pp. 1314–1323, 2014.

[28] A. D. Henriksen and A. J. Traynor, “A practical R & D project-selection scoring tool,” *{IEEE} Trans. Eng. Manag.*, vol. 46, no. 2, pp. 158–170, 1999.

[29] R. C. McNally, S. S. Durmuşoğlu, and R. J. Calantone, “New product portfolio management decisions: Antecedents and consequences,” *J. Prod. Innov. Manag.*, vol. 30, no. 2, pp. 245–261, 2013.

[30] P. Patanakul, “Key drivers of effectiveness in managing a group of multiple projects,” *IEEE Trans. Eng. Manag.*, vol. 60, no. 1, pp. 4–17, 2013.

[31] R. Sperry and A. Jetter, “Theoretical framework for managing the front end of innovation under uncertainty,” *PICMET Portl. Int. Cent. Manag. Eng. Technol. Proc.*, pp. 2021–2028, 2009.

[32] M. Martinsuo, “Project portfolio management in practice and in context,” *Int. J. Proj. Manag.*, vol. 31, no. 6, pp. 794–803, 2013.

[33] Q. Tian, J. Ma, J. Liang, R. C. W. Kwok, and O. Liu, “An organizational decision support system for effective R&D project selection,” *Decis. Support Syst.*, vol. 39, no. 3, pp. 403–413, 2005.

[34] H. Eilat, B. Golany, and A. Shtub, “Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology,” *Eur. J. Oper. Res.*, vol. 172, no. 3, pp. 1018–1039, 2006.

[35] S. Coldrick, P. Longhurst, P. Ivey, and J. Hannis, “An R&D options selection model for investment decisions,” *Technovation*, vol. 25, no. 3, pp. 185–193, 2005.

[36] K. Katz and T. Manzione, “Maximize Your ‘Return on Initiatives’ with the Initiative Portfolio Review Process,” *Haarvard Bus. Rev.*, pp. 14–16, 2008.

[37] A. Wilkinson, M. Mayer, and V. Ringler, “Collaborative futures: Integrating foresight with design in large scale innovation processes-seeing and seeding the futures of Europe,” *J. Futur. Stud.*, vol. 18, no. 4, pp. 1–26, 2014.

[38] R. Miller, “Learning, the Future, and Complexity. An Essay on the Emergence of Futures Literacy,” *Eur. J. Educ.*, vol. 50, no. 4, pp. 513–523, 2015.

[39] M. Silva, “Thinking Outside the Triangle: Using Foresight in Project Environments to Deliver a Resilient Tomorrow,” *IPMA Expert Semin. 2016*, pp. 1–14, 2016.

[40] B. V. Smith and M. G. Ierapepritou, “Modeling and optimization of product design and portfolio management interface,” *Comput. Chem. Eng.*, vol. 35, no. 11, pp. 2579–2589, 2011.

[41] et all Rogério dos Santos Alves; Alex Soares de Souza, “Case Study: An Intelligent Decision- Support System,” *Igarss 2014*, vol. 20, no. 1, pp. 1–5, 2014.

[42] A. Arbussa, A. Bikfalvi, and P. Marquès, “Strategic agility-driven business model renewal: the case of an SME,” *Manag. Decis.*, vol. 55, no. 2, pp. 271–293, 2017.

[43] M. W. Staniewski, R. Nowacki, and K. Awruk, “Entrepreneurship and innovativeness of small and medium-sized construction enterprises,” *Int. Entrep. Manag. J.*, vol. 12, no. 3, pp. 861–877, 2016.

[44] N. Lee, H. Sameen, and M. Cowling, “Access to finance for innovative SMEs since the financial crisis,” *Res.*

Policy, vol. 44, no. 2, pp. 370–380, 2015.

[45] Y. Liao and J. Barnes, “Knowledge acquisition and product innovation flexibility in SMEs,” *Bus. Process Manag. J.*, vol. 21, no. 6, pp. 1257–1278, 2015.

[46] V. Kokotovich and C. P. Killen, “Enhancing Design Project Review Board Effectiveness Through a Visual Collaborative Approach,” *Int. Conf. Coop. Des. Vis. Eng.*, pp. 118–125, 2016.

[47] N. O’Regan, M. Sims, and A. Ghobadian, “High Performance: Ownership and Decision-making in SMEs,” *Manag. Decis.*, vol. 43, no. 3, pp. 382–396, 2005.

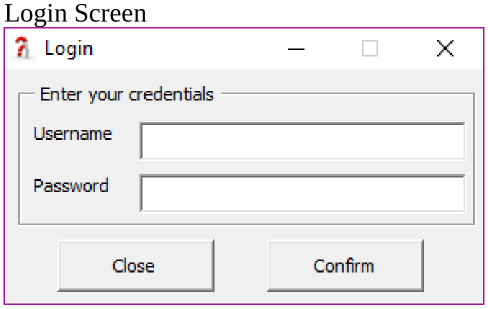
[48] Z. Turskis, E. K. Zavadskas, J. Antucheviciene, and N. Kosareva, “A Hybrid Model Based on Fuzzy AHP and Fuzzy WASPAS for Construction Site Selection Methodology,” *Int. J. Comput. Commun. Control*, vol. 10, no. 6, pp. 873–888, 2015.

[49] J. Davis, a MacDonald, and L. White, “Problem-structuring methods and project management: an example of stakeholder involvement using Hierarchical Process Modelling methodology,” *J. Oper. Res. Soc.*, vol. 61, no. 6, pp. 893–904, Apr. 2010.

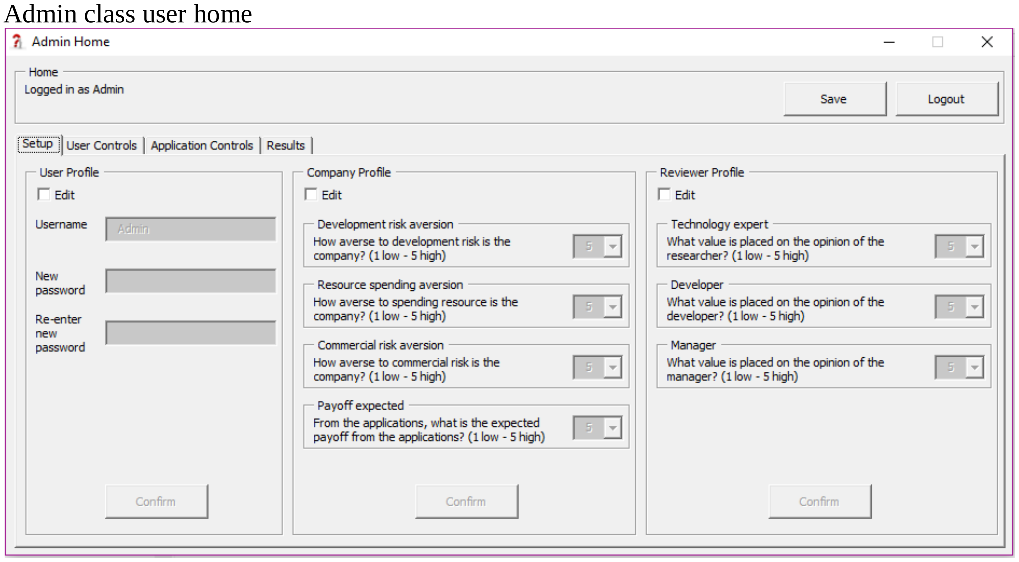
[50] J. Daniels, P. W. Werner, and a. T. Bahill, “Quantitative methods for tradeoff analyses,” *Syst. Eng.*, vol. 4, no. 3, pp. 190–212, 2001.

APPENDICES

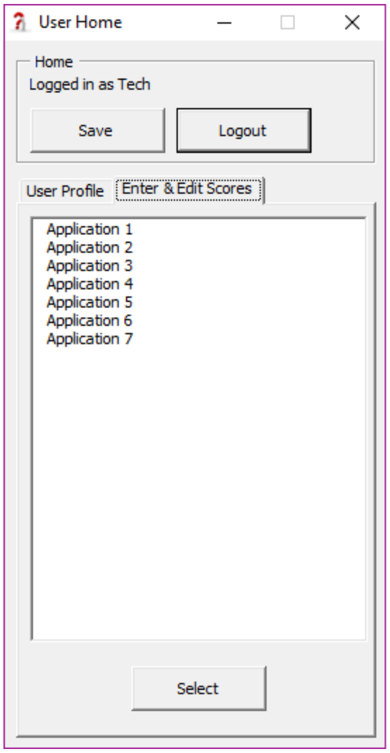
Login Screen



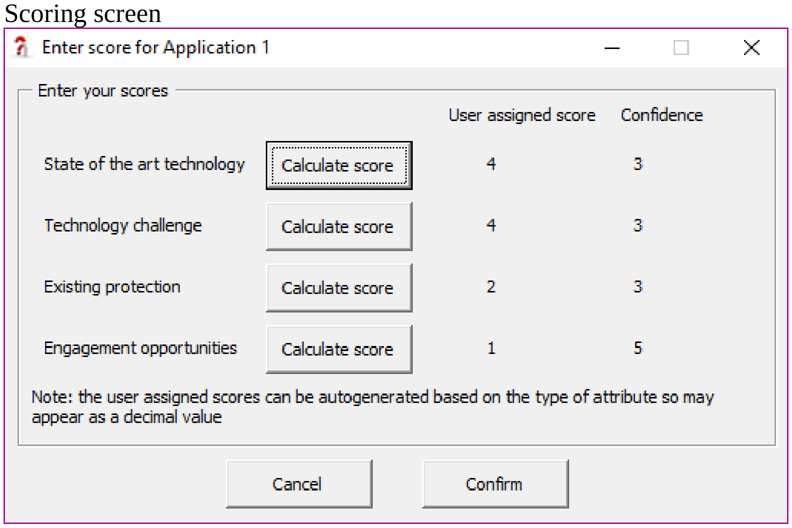
Admin class user home



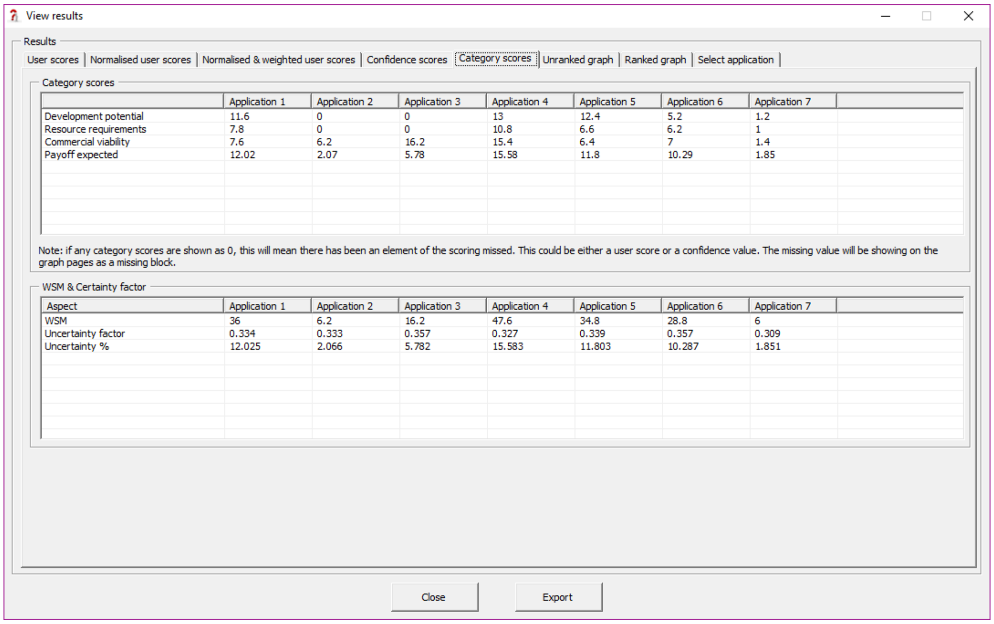
Reviewer class user home



Scoring screen



Results breakdown


View results

Results

User scores | Normalised user scores | Normalised & weighted user scores | Confidence scores | Category scores | Unranked graph | Ranked graph | Select application

Category scores

	Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7
Development potential	11.6	0	0	13	12.4	5.2	1.2
Resource requirements	7.8	0	0	10.8	6.6	6.2	1
Commercial viability	7.6	6.2	16.2	15.4	6.4	7	1.4
Payoff expected	12.02	2.07	5.78	15.58	11.8	10.29	1.85

Note: if any category scores are shown as 0, this will mean there has been an element of the scoring missed. This could be either a user score or a confidence value. The missing value will be showing on the graph pages as a missing block.

WSM & Certainty factor

Aspect	Application 1	Application 2	Application 3	Application 4	Application 5	Application 6	Application 7
WSM	36	6.2	16.2	47.6	34.8	28.8	6
Uncertainty factor	0.334	0.333	0.357	0.327	0.339	0.357	0.309
Uncertainty %	12.025	2.066	5.782	15.583	11.803	10.287	1.851

Close | Export

Results export